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Analyzing the Performance of Channel in Underwater Wireless Sensor Networks(UWSN)

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Abstract

Underwater wireless sensor networks is composed of a variable number of sensor networks that communicated with each other using acoustic signal and the sensor nodes are deployed in some special underwater environment for monitoring tasks. Designing underwater feasible channel is essential and turns out a great challenge for the characteristics of underwater environment. The motivation for studying the channel performance in UWSN is to provide a reference for deploying sensor nodes in underwater environment. The underwater acoustic channel exhibits multi-path propagation that results in fading and phase fluctuations at the receivers. Doppler effect is another phenomenon that is observed due the movement of both the transmitter and the receiver. Sound speed and complex noise in underwater environment are also the vital factors for modeling good performance channel. In this paper, it analyzes and simulates the characteristics of underwater sensor networks. It concludes that the relation between multi-path fading and distance, frequency and the influences of Doppler effect, delay spread.

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Keywords: underwater signal propagation, underwater channel, multi-path fading, Doppler effect, wireless sensor networks;

1. Introduction

Underwater wireless sensor networks(UWSN) have a broad range of possible applications in environmental research, assisted navigation, pollution monitoring, real-time control of autonomous underwater vehicles(AUV), and also offshore exploration. To make these applications feasible, there is a need for statistical characterization of the acoustic channels. However, UWSN channel is one of the most challenging wireless communication channels. First, UWSN experience severe communication problems due to the large signal attenuation and ambient noise in water. Furthermore, their obstacle is also the fact that acoustic signals propagate through water at a low speed, and the acoustic signals are greatly affected by the reflections from the ocean surface, floor and by variations in the speed of sound at different water

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depths. All these variations in the medium cause the path-dependent Doppler and angle spreading, which results in a time-varying, delay, multi-path fading channel impulse response with low delay spreads^[1]. This paper is organized as follows. Section 2 discusses the related work on the UWSN channel. The underwater environment considerations and simulations are elaborated in Section 3. Final conclusions are drawn in Section 4.

2. Related work

Due to very large operational and equipment costs involved in the setup of large scale test beds, simulation is still the most flexible tool for extensive characterization of underwater acoustic networks. Several underwater communication models in the literature are proposed for acoustic underwater link. They reported several environmental and channel parameters as salinity, temperature, depth, noise, spreading loss etc, with different detail levels. Most of these proposals are validated by means of either simulation tools or statistic models from the literature. In [2], the model proposed by Harris and Zorzi is fundamental to the work of underwater communication models in terms of simulation. This model divides the underwater model into four parts namely, physical, channel, propagation and also modulation models. However, only considering single-path propagation in [3], this model may help provide an order-of-magnitude prediction of the channel behavior and of the networking protocols operating on top of it, but usually assume the speed of sound as constant throughout the water column, and in addition do not include such important propagation effects as multi-path fading and time-varying channel behaviors. Other than that, there exist several deterministic and statistical simulation models for underwater wireless channel^[4,5]. A statistical framework for shallow water acoustic channels, i.e., correlation functions, Doppler power spectral density, transmission delay and etc.. To consider the challenges that underwater environment poses such as the sound speed, noise, multi-hop fading and Doppler effect etc., modeling the channel with correct environment parameters.

3. Environment Considerations for Simulation

The volume properties and boundaries in UWSN form a complex medium for the propagation of acoustic signal. Typical frequencies associated with underwater acoustics are between 10HZ and 1MHZ. The sound speed is 1500m/s which is lower than radio and optical propagation^[8]. The features of the acoustic channel are large propagation delay(0.67s/km), multi-path fading, Doppler effect.

3.1. Sound Speed

The sound speed in the underwater depends on the water properties such as salinity, temperature and depth. The sound speed profile(SSP) may be constructed from any number of actual data points and then subjected to a fitting algorithm to produce a smoother graph. Usually, measurements values are available for salinity and temperature at various depths. In this case, SSP can be calculated as follows:

$$c = 1449.2 + 4.6T - 0.055T^2 + 0.00029T^3 + (1.34 - 0.010T)(S - 35) + 0.06z \quad (1)$$

where c is the speed of sound in m/s , S is the salinity, T is the temperature of underwater and z is the depth in meters^[7].

From Fig.1, we can see that the relationship between depth and sound speed with different temperatures. A sound speed selected for a specific region will produce an output that will better match the actual underwater acoustic wireless sensor network environment. A larger depth causes a higher sound speed in the underwater. Meanwhile, the sound speed is higher as the temperature is ascending. In

this simulation, the temperatures are varied with certain range of the depth. The sound speed curve is linear to the depth when the value of the temperature is kept constant.

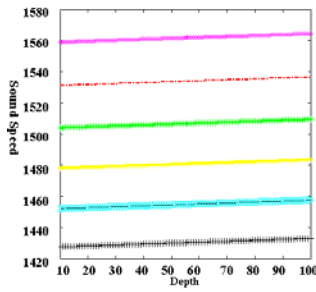


Fig.1. Sound Speed against Depth Profile

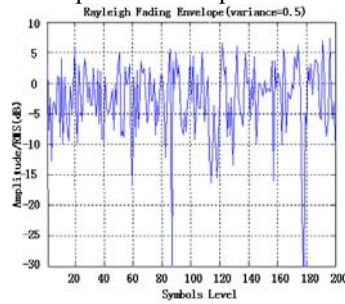


Fig.2 Rayleigh Fading Envelope

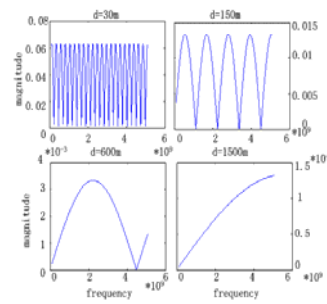


Fig.3 frequency characteristics of multi-path fading at four locations

3.2. Noise Conditions

Noise in the underwater channel comes from various sources which include surface wind, thermal activity in below water, traffic noise from ships and activities. For some typical monitoring environment, each of these noise sources will need to be described so as to capture the specific underwater noise characteristics. The noise in underwater environment can be divided into four major factors: turbulence(N_t), shipping(N_s), wind(N_w), and thermal(N_{th})^[3].

3.3. Rayleigh and Multi-path fading

Boundaries at the channel surface and bottom reflect an acoustic signal, resulting in multiple travel paths between transmitter and receiver. The receiver can thus acquire signals arriving on different paths. One common stochastic model used to characterize a multi-path fading environment is Rayleigh model. The characteristics of reflections at the boundaries depend on the value of the Rayleigh parameter given by^[8]:

$$R = 2\pi c \sin \theta / \lambda \quad (2)$$

where c is the rms surface wave-height(crest to trough), θ is the grazing angle of the acoustic ray, λ is the wave length.

Rayleigh random variables can be generated using Gaussian random variables with common variance. In our simulation, variance is set 0.5. Rayleigh fading of the channel is obtained by making use of QPSK signals modulated with pseudo noise like m-sequences. x axis describes symbol level, while y axis presents amplitude (dB). The Rayleigh profile is plotted out and presented in Fig.2.

We plot the magnitude of against the frequency for four distances $w=30m, 150m, 600m, 1500m$ in Fig.3. It describes the relationship between frequency and magnitude in different locations. From the profile, we can observe that amplitudes and arrival times of multi-path arrivals depend on locations of transmitter and receiver in the underwater wireless sensor networks, and the received signal strength will also depend on the locations of transmitter and receiver.

3.4. Doppler effects

The mean frequency shift of a received signal due to relative motion between the transmitter and the receiver over some window of time is considered as the Doppler shift, whereas the fluctuations of frequency around this Doppler shift is referred as the Doppler spread. Doppler spread arises from

variations in the height of the surface reflection point, which is caused by wind driven waves. These will cause time variations in the direct and reflected path lengths. As a result, the signal will be phase modulated and the bandwidth of this phase modulation will be known as the estimated Doppler spread f_d [10]. Doppler shifts and spread indicates the time variations in the multiple models. These Doppler effects increases with the centre frequency, transmitter and carrier frequency, radial speed away from the transmitter and sound speed respectively.

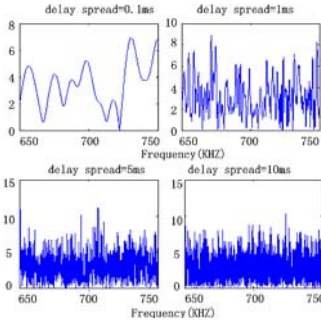


Fig.4 absolute values of

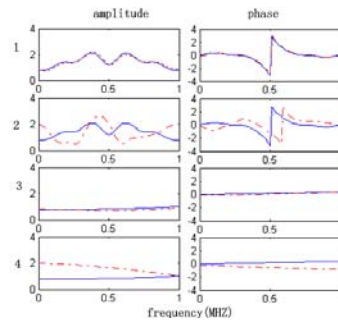


Fig.5 Doppler-delay vs frequency

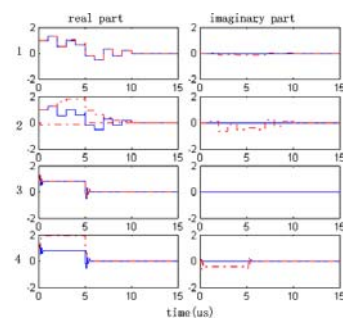


Fig.6 Doppler-delay vs time

transfer functions of different delay spread

In a time varying multi-path UWSN, the sensor nodes received signal is as follows:

$$y(t) = H(w,t)e^{j\omega t} \quad \text{where} \quad H(w,t) = \sum_{n=1}^N a_n e^{-j\omega\tau_n + j\omega_n t} \quad (3)$$

is the time varying spectrum. Consider a signal with multiple frequency components

$$s(t) = \frac{1}{2\pi} \int_{-\infty}^{\infty} S(w)e^{j\omega t} dw \quad (4)$$

The time varying spectrum of received signal is $S(w)H(w,t)$ and the time-domain received signal is as follows:

$$y(t) = \frac{1}{2\pi} \int_{-\infty}^{\infty} S(w)H(w,t)e^{j\omega t} dw = \sum_{n=1}^N a_n \left(\frac{1}{2\pi} \int_{-\infty}^{\infty} S(w)e^{j\omega(t-\tau_n) + j\omega_n t} dw \right) \quad (5)$$

where n is the number of transmitters-receiver pairs, τ_n is the delay spread, a_n is the Doppler spread.

The absolute value of the transfer functions for different delay spreads are plotted against the frequency is illustrated in Fig.4. In this case, delay spread τ_n is set $0.1 \mu s$, a cycle of variation is of the order of 5MHz. Meanwhile, for the other cases with delay spread = $1 \mu s$, $5 \mu s$, $10 \mu s$, a cycle of variation is of the order of 1MHz, 0.2MHz or 0.1MHz respectively. n is set 40 pairs in the simulation. Fig.4 indicates that the magnitude of transfer function varies by the frequency when delay spread is constant. As can be observed that, when the delay spread enhances, the magnitude of transfer function is slowly increasing.

The profile describes four cases with different combinations of delay spreads and Doppler spreads. In each case, there are 6 pairs and amplitudes of these 6 pairs are: $a_n = [1, 0.3, -0.8, 0.5, -0.4, 0.2]$

The Doppler shifts are:

Cases 1 and 3 are with small Doppler spread $w_n = [0, 2\text{Hz}, 10\text{Hz}, 6\text{Hz}, 8\text{Hz}, 4\text{Hz}]$

Cases 2 and 4 are with large Doppler spread $w_n = [0, 20\text{Hz}, 100\text{Hz}, 60\text{Hz}, 80\text{Hz}, 40\text{Hz}]$

The transmission time delays are:

Cases 1 and 2 are with large delay spread $\tau_n = [0, 1\mu\text{s}, 2\mu\text{s}, 3\mu\text{s}, 4\mu\text{s}, 5\mu\text{s}]$;

Cases 3 and 4 are with small delay spread $\tau_n = [0, 0.1\mu\text{s}, 0.2\mu\text{s}, 0.3\mu\text{s}, 0.4\mu\text{s}, 0.5\mu\text{s}]$;

In Fig. 5 the transfer function (amplitude and phase) for frequencies from -1MHz to $+1\text{MHz}$ for two the observation times at $t_0 = 0\text{sec}$ and 20ms . The dash-dot line represents the observation made at $t_0 = 20\text{ms}$, while solid line describes the observation made at $t_0 = 0$. As can be seen from the Fig.5, the larger Doppler spread causes faster variation rate with respect to the observation time and the larger delay spread causes faster variation rate with respect to frequency.

Consider $s(t)$ is 1 between $t_0 + 5\mu\text{s}$ and is zero elsewhere. In Fig. 6 the received signal $y(t)$ for the two observation times at $t_0 = 0$ and 20ms . The dash-dot line also represents the observation made at $t_0 = 20\text{ms}$, while solid line describes the observation made at $t_0 = 0$. Fig.6 describes real and imaginary part of output signal $y(t)$. Fig.5 and Fig.6 show that the relation of Doppler effect against frequency and time. These relations provide some references for designing appropriate UWSN model.

4. Conclusions

With the expense of monitoring underwater filed sensor networks, it is imperative that accurate models be available to testing in a simulation environment. Our analyzing of performance of the acoustic parameter was motivated by our need to design robust and feasible underwater channel modeling in Matlab and build suitable topology architecture in UWSN. The analysis of the channel and topology architecture strongly depended on sound speed vs distance, multi-path fading vs distance(frequency), delay spread vs distance(frequency), Doppler effect vs distance(frequency).

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